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Flavor changing neutral currents in SU(3) X U(1) models

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Flavor changing neutral currents in $SU(3) \otimes U(1)$ models

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We consider flavor changing neutral current effects coming from the Z' exchange in 3-3-1 models. We show that the mass of the extra neutral vector boson may be less than 2 TeV.

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Recently it was proposed an electroweak model based on the $SU(3)_L \otimes U(1)_N$ gauge symmetry [1, 2]. The leptons are treated democratically with the three generations transforming as $(\mathbf{3}, 0)$ but with one quark generation (it does not matter which one) transforms differently from the other two. This condition arise because the model in order to be anomaly free must contain the same number of triplets as antitriplets. Hence, the number o generations is related to the number of quark colors.

In Ref. [1] the first generation is the one which transforms differently than the second and the third ones. On the other hand, in Ref. [2] it was the third generation which was treated differently. It was claimed that neutral currents could discriminate between both choices of representation content [3].

The GIM mechanism in several 3-3-1 models was consider in Ref. [4]. Here we will turn back to the problem of flavor changing neutral currents, in particular we will show that the difference in the choice of the quark representations is less important than it was thought at first sight. The lower bound for the mass of Z' was overestimated in Ref. [1].

We will use the notation of Ref. [1] but our results are trivially written in the notation of Ref. [2]. We also do not consider the lepton sector here because there is no difference there.

Let us start by written the quark representations: one of the generation transform as $(\mathbf{3}, 0)$, with the second entry denoting $U(1)_N$ charges,

$$Q_{1L} = \begin{pmatrix} u_1 \\ d_1 \\ J \end{pmatrix} \tag{1}$$

and the other two as $(\mathbf{3}^*, -1/3)$:

$$Q_{2L} = \begin{pmatrix} j_1 \\ u_2 \\ d_2 \end{pmatrix}, \qquad Q_{3L} = \begin{pmatrix} j_2 \\ u_3 \\ d_3 \end{pmatrix} \tag{2}$$

The exotic quark J has charge $5/3$ and j_i, $i = 1,2$ have both charge $-4/3$. Eq. (1) denotes the first or the third generation. At this stage it does not matter.

Denoting $U' = (u_1, u_2, u_3)^T$ and $D' = (d_1, d_2, d_3)^T$ the symmetry eigenstates of charge $2/3$ and $-1/3$ respectively, we can write the neutral currents with the extra neutral vector boson Z' in this basis [5]

$$\mathcal{L}_{Z',U} = -\frac{g}{2\cos\theta_W}(\bar{U}'_L\gamma^\mu Y_L^U U'_L + \bar{U}'_R\gamma^\mu Y_R^U U'_R)Z'_\mu + H.c. \tag{3}$$

with

$$Y_L^U = -\frac{1}{2\sqrt{3}h(x)}\begin{pmatrix} 1 & 0 & 0 \\ 0 & -h^2(x)/2 & 0 \\ 0 & 0 & -h^2(x)/2 \end{pmatrix} \tag{4}$$

and

$$Y_R^U = -\frac{2x}{\sqrt{3}h(x)}\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{5}$$

where we have defined $h(x) = (1-4x)^{\frac{1}{2}}$ and $x \equiv \sin^2\theta_W$.

In the charge $-1/3$ sector we have,

$$\mathcal{L}_{Z',D} = -\frac{g}{2\cos\theta_W}(\bar{D}'_L\gamma^\mu Y_L^D D'_L + \bar{D}'_R\gamma^\mu Y_R^D D'_R)Z'_\mu + H.c. \tag{6}$$

with

$$Y_L^D = -\frac{1}{2\sqrt{3}h(x)}\begin{pmatrix} 1 & 0 & 0 \\ 0 & -2(1-2x) & 0 \\ 0 & 0 & -2(1-2x) \end{pmatrix} \tag{7}$$

and

$$Y_R^D = \frac{2x}{\sqrt{3}h(x)}\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{8}$$

In order to generate quark masses it is necessary to introduce the following Higgs multiplets

$$\eta \sim (\mathbf{3}, 0), \quad \rho \sim (\mathbf{3}, 1), \quad \chi \sim (\mathbf{3}, -1), \tag{9}$$

and a sextet $(\mathbf{6}, 0)$ which is necessary in order to give the leptons a mass [6], but we will not consider it here because this sextet does not couple to the quarks.

The Yukawa couplings for the charged $2/3$ and $-1/3$ sector are

$$\begin{aligned} -\mathcal{L}_Y = {} & \bar{Q}_{1L}G_{1\alpha}U'_{\alpha R}\eta + \tilde{G}_{1\alpha}D'_{\alpha R}\rho \\ & + \bar{Q}_{iL}(F_{i\alpha}U'_{\alpha R}\rho^* + \tilde{F}_{i\alpha}D'_{\alpha R}\eta^*) + H.c., \end{aligned} \tag{10}$$

with $i = 1,2$ and $\alpha = 1,2,3$. $SU(3)$ indices have been suppressed and η^*, ρ^* denote the respective antitriplets [7].

From Eq. (10) it is straightforward to write the mass term

$$-\mathcal{L}_m = v_\eta \bar{U}'_{\alpha L}\Gamma^U_{\alpha\beta}U'_{\beta R} + v_\rho \bar{D}'_{\alpha L}\Gamma^D_{\alpha\beta}D'_{\beta R} + H.c., \tag{11}$$

where v_η, v_ρ are the vacuum expectation value of the neutral components of η and ρ respectively and with the matrices

$$\Gamma^U = \begin{pmatrix} G_{11} & G_{12} & G_{13} \\ F_{12}r & F_{22}r & F_{23}r \\ F_{13}r & F_{32}r & F_{33}r \end{pmatrix}, \quad \Gamma^D = \begin{pmatrix} \tilde{G}_{11} & \tilde{G}_{12} & \tilde{G}_{13} \\ \tilde{F}_{21}/r & \tilde{F}_{22}/r & \tilde{F}_{23}/r \\ \tilde{F}_{13}/r & \tilde{F}_{32}/r & \tilde{F}_{33}/r \end{pmatrix}, \tag{12}$$

where we have defined $r = v_\rho/v_\eta$. The mass matrices can be diagonalized by making the biunitary transformations

$$U'_L = V_L^U U_L, \quad U'_R = V_R^U U_R, \tag{13}$$

$$D'_L = V_L^D U_L, \quad D'_R = V_R^D D_R, \tag{14}$$

where $U = (u, c, t)^T$ and $D = (d, s, b)^T$ are the mass eigenstates if we assume that the first generation is the one which transform differently or $U = (t, u, c)^T$, $D = (b, d, s)^T$ if it the third generation which is treated in a different way. Both choices will differ in the parameterization of the matrices in Eqs. (13) and (14). Here, we will choose the first alternative.

Using (13) and (14) in Eqs. (3) and (6) respectively we see that

$$Y_L^U \to V_L^{U\dagger} Y_L^U V_L^U, \quad Y_R^U \to V_R^{U\dagger} Y_R^U V_R^U = Y_R^U. \tag{15}$$

$$Y_L^D \to V_L^{D\dagger} Y_L^D V_L^D, \quad Y_R^D \to V_R^{D\dagger} Y_R^D V_R^D = Y_R^D, \tag{16}$$

We see that the right handed neutral currents are diagonal but not the left-handed ones.

Next, we want to consider some constraints that arise from experimental data in the $K^0 - \bar{K}^0$, and $D^0 - \bar{D}^0$ systems. Similar consideration could be made in the $B^0 - \bar{B}^0$ system but we will not treat this issue here.

In particular, from Eqs. (3), (6), (15) and (16) we write the vertices $\bar{s}\gamma^\mu d$ and $\bar{u}\gamma^\mu c$,

$$\mathcal{L}_{uc} = \frac{g}{4\sqrt{3}h(x)c_W}[V_{Luu}^{U*}V_{Luc}^U - \frac{1}{2}h^2(x)(V_{Lcu}^{U*}V_{Lcc}^U + V_{Ltu}^{U*}V_{Ltc}^U)]\bar{u}_L\gamma^\mu c_L Z'_\mu + H.c. \tag{17}$$

and

$$\mathcal{L}_{sd} = \frac{g}{4\sqrt{3}h(x)c_W}[V_{Lds}^{D*}V_{Ldd}^D - 2(1-2x)(V_{Lss}^{D*}V_{Lsd}^D + V_{Lbs}^{D*}V_{Lbd}^D)]\bar{u}_L\gamma^\mu c_L Z'_\mu + H.c. \tag{18}$$

Using the unitarity condition for the $V_L^{U,D}$ matrices we can rewrite (17) and (18) as

$$\mathcal{L}_{uc} = \frac{g}{4\sqrt{3}h(x)c_W}(1 + \frac{1}{2}h^2(x))V_{uu}^{U*}V_{Luc}^U\bar{u}_L\gamma^\mu c_L Z'_\mu, \tag{19}$$

and

$$\mathcal{L}_{sd} = \frac{g}{4\sqrt{3}h(x)c_W}(3 - 4x)V_{Lsd}^{D*}V_{Ldd}^D\bar{s}_L\gamma^\mu d_L Z'_\mu \tag{20}$$

respectively. From (19) and (20) we obtain the effective Lagrangian

$$\mathcal{L}_{\Delta c=2}^{eff} = \frac{G_F M_Z^2}{6\sqrt{2}M_{Z'}^2}\mathcal{O}_{uc}^2[\bar{u}_L\gamma^\mu c_L]^2 \tag{21}$$

and

$$\mathcal{L}_{\Delta s=2}^{eff} = \frac{G_F M_Z^2}{6\sqrt{2}M_{Z'}^2}\mathcal{O}_{sd}^2[\bar{s}_L\gamma^\mu d_L]^2 \tag{22}$$

where we have defined

$$\mathcal{O}_{uc} = \left(\frac{1 + \frac{1}{2}h^2(x)}{h(x)}\right) V_{Luu}^{U*}V_{Luc}^U, \tag{23}$$

and

$$\mathcal{O}_{sd} = \left(\frac{3 - 4x}{h(x)}\right) V_{Lds}^{D*}V_{dd}^D. \tag{24}$$

Since we are interested just to give an order of magnitude of the parameters in (21) and (22) we can assume the vacuum dominance in the intermediate states and PCAC to obtain the $D_1^0 - D_2^0$ and $K_L - K_S$ mass differences [10]. Defining $\Delta m_K = m_{K_L} - m_{K_S}$ and $\Delta m_D = m_{D_1^0} - m_{D_2^0}$ we obtain

$$\frac{\Delta m_D}{m_D} = \frac{2}{3}B_D f_D^2 \frac{G_F M_Z^2}{6\sqrt{2}M_{Z'}^2}\left[\frac{1 + \frac{1}{2}h^2(x)}{h(x)} V_{Luu}^{U*}V_{Luc}^U\right]^2 \tag{25}$$

and

$$\frac{\Delta m_K}{m_K} = \frac{2}{3}B_K f_K^2 \frac{G_F M_Z^2}{6\sqrt{2}M_{Z'}^2}\left[\frac{3 - 4x}{h(x)} V_{Lds}^{D*}V_{dd}^D\right]^2 \tag{26}$$

We will use the "Bag constants" B_D [9] and B_K equal to one. The experimental value for these mass difference are [11]

$$\Delta m_D < 1.3 \times 10^{-10}\,\mathrm{MeV}, \quad \Delta m_K = (3.522 \pm 0.016) \times 10^{-12}\,\mathrm{MeV}. \tag{27}$$

Using $m_K = 497.676 \pm 0.030$ MeV and $m_D = 1864.1 \pm 0.1$ MeV and not considering the experimental error, since we are only interested in orders of magnitude, we obtain

$$\frac{\Delta m_D}{m_D} = 7.0 \times 10^{-13}, \quad \frac{\Delta m_K}{m_K} = 7.08 \times 10^{-15} \tag{28}$$

Assuming that the contribution to the $\Delta m_D/m_D$ and $\Delta m_K/m_K$ coming from the Z' exchange i.e., (25) and (26) are less than the experimental values given in (28) we obtain

$$M_{Z'} > 4.16 \times 10^4 (V^{U*}_{Luu} V^U_{Luc})\,\mathrm{GeV}, \tag{29}$$

and

$$M_{Z'} > 1.5 \times 10^6 (V^{D*}_{Lds} V^D_{dd})\,\mathrm{GeV} \tag{30}$$

We have used $f_D \approx 200$ MeV and $f_K \approx 161$ MeV, $x \approx 0.2325$ and all other values from Ref. [11]. We see from (29) and (30) that it is possible to have a neutral boson Z' with a mass of about 1.5 GeV if

$$V^{U*}_{Luu} V^U_{Luc} \sim 10^{-2}, \qquad V^{D*}_{Lds} V^D_{Ldd} \sim 10^{-3}. \tag{31}$$

On the other hand, the charged current with the $W^\pm$ boson is written as $\bar{D}_L \gamma^\mu V_{KM} U_L$ with the matrix V_{KM} is the Cabibbo-Kobayashi-Maskawa matrix defined as

$$V_{CKM} = V^{D\dagger}_L V^U_L. \tag{32}$$

Hence, the values in (31) must be consistent with the condition (32). In principle this is possible since we do not know the values of the matrices $V^{U,D}_L$. In the standard

model both matrices $V^{U,D}_L$ appear only in the combination given in (32) and for this reason it is a usual convention to assume that $V_{KM} = V^{D\dagger}_L$, that is, $V^U_L \equiv \mathbf{1}$. In the model of Refs. [1, 2] this is not the case as we can see from (17) and (18). Hence, both matrices survive in different places of the Lagrangian and it is too strong to assume that $V^U_L \equiv \mathbf{1}$ [8]. Assuming $V^U_L \equiv \mathbf{1}$ is not stable against radiative corrections since all matrix elements evolve with energy according with the renormalization group equation [12]. Notice the matrices $V^{U,D}_R$ will appear in the Yukawa interactions.

We see from (29)–(31) that it is not so important, as we could think at first sight, which quark generation transforms differently from the other two. In any case, the Z' mass could be less than 2 TeV.

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REFERENCES

[1] F. Pisano and V. Pleitez, Phys. Rev. D**46**, 410 (1992).

[2] P.H. Frampton, Phys. Rev. Lett. **69**, 2889(1992).

[3] D. Ng, The electroweak theory of $SU(3) \otimes U(1)$, preprint TRI-PP-92-125, December 1993.

[4] J.C. Montero, F. Pisano e V. Pleitez, Phys. Rev. D**47**, 2918(1993).

[5] The neutral currents coupled with the Z boson are diagonal in the flavor space and we will not consider them here. See Ref. [4].

[6] R. Foot, O. F. Hernandez, F. Pisano and V. Pleitez, Phys. Rev. D**47**, 4158(1993).

[7] See the Appendix of Ref.[4]

[8] One of us (V.P.) would like to thank D. Dunn for calling his attention to this point.

[9] R.J. Morrison and M.S. Witherell, Annu. Rev. Nucl. Part. Sci. **39**, 183(1989).

[10] M.K. Gaillard and B.W. Lee, Phys. Rev. D**10**, 897(1974).

[11] Particle Data Group, Phys. Rev. D **45**, Part II(1992).

[12] E. Ma and S. Pakvasa, Phys. Lett. **86B**, 43(1979); Phys. Rev. D**20**, 2899(1979); K. Sasaki, Z. Phys. C**32**, 149(1986), K.S. Babu, Z. Phys. C**35**, 6991987); V. Barger, M.S. Berger and P. Ohmann, Phys. Rev. D**47**, 2038(1993).